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SMALL AREA HIGHWAY PROGRAM

Analytical Report on Data Collected
During the First Three Years of the Cooperative Program
Between
Montana State Highway Commission and U.S. Geological Survey

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ANALYTICAL REPORT ON DATA COLLECTED DURING THE FIRST THREE YEARS OF THE COOPERATIVE PROGRAM BETWEEN MONTANA STATE HIGHWAY COMMISSION AND U.S. GEOLOGICAL SURVEY

Introduction.--In May 1958, an open-file report entitled, "Floods in Eastern Montana, Magnitude and Frequency", was published by the U. S. Geological Survey in cooperation with the Montana State Highway Commission. The report presented a method of determining the magnitude and frequency of expected floods applicable to any area from 100 to 3,000 square miles in most of eastern Montana. A composite frequency curve was developed that expressed the relation of floods having a recurrence interval from 1.05 to 20 years to the mean annual flood. The composite curve was based on the combined frequency curves for 16 stations having 5 or more years of record. An equation was derived expressing the relation between mean annual flood, drainage area, and mean elevation of the desired basin.

The cooperative agreement between the Montana State Highway Commission and the U. S. Geological Survey stipulated that an annual report be made of the progress in the collection of data at the crest-stage gage stations. In addition to the yearly progress report, it was agreed that an analysis of the data be made at the midpoint of the six year program. The object of this interim report is to present the results of that analysis.

The data collected have been used to expand the range of the report of May 1958, mentioned above, to cover drainage areas as small as one square mile.

Data used.--Approximately 40 crest-stage gages have been in operation since the summer of 1955 for the purpose of recording peak stages of flow. Of these, 15 stations were considered for use at this time; the remainder were not used because rating curves have not been defined. Further examination resulted in the elimination of 6 more stations, mainly because it appeared that the mean annual flood determined on the basis of the very short period of record was not reasonable due to unusual occurrences having been experienced at those stations.

Records for 15 stations used in the original report were also used in this analysis. Little Beaver Creek near Marmarth, N. Dak., did not correlate with the remainder of the stations when the different basin characteristics were introduced, and therefore had to be eliminated in this analysis. A total of 24 stations, 15 long-term stations and 9 short-term stations were used in the multiple correlation covering a range in drainage area from 0.8 to 3,000 square miles. All of the stations used are listed in table 1.

Flood frequency relations.--Various techniques for determining the frequency and magnitude of floods at a single gaging station from past records have been developed; however, only two methods were used in this report: the partial duration series and the annual flood series. It has been found that the partial duration series and the annual flood series give essentially identical results for intervals greater than ten years. For this reason, the annual flood series was used for the 15 long-term stations to determine the mean annual

flood. The partial duration series was necessarily used for the crest-stage gage stations to determine the mean annual flood. The mean annual flood for each of the 24 stations is tabulated in table 1.

Composite frequency curve.--Before a group of stations can be combined, a test of homogeneity is considered necessary to insure that all of the records are selected from a region with uniform flood-frequency characteristics. This test for homogeneity requires that not only the mean annual flood be determined, but also the ten-year flood at each station be determined. Due to the shortness of record at the crest-stage gage sites, it was impossible, at this time, to determine the ten year flood and therefore impossible to test each station for homogeneity. It is felt, however, that at the end of six years the ten year flood can be determined from an extension of the flood frequency curve. In order to make use of available data it was assumed that all of the stations are homogeneous.

The long-term stations were grouped together for the purpose of computing average flood ratios for each recurrence interval. This composite flood-frequency curve is shown in figure 1, and is the same as that computed for the original report.

A comparison between the long-term stations and the short-term stations for the common period of 1956-58 was deemed necessary. Of the 15 long-term stations, data for only 9 stations were available at this time. However, it was felt that these were a sufficient number of stations to be representative for that group. Figure 2 shows the composite frequency curves for the 9 crest-stage gage sta-

tions, the 9 long-term stations, and the curve from figure 1, all plotted on basis of the partial duration series. It can be seen that the long-term and short-term stations compared quite favorably for a ratio to the mean annual flood above 1, while below 1 the seemed to diverge. The divergence of the lower portion of the curve for the 9 long-term stations reflects a very dry period in the eastern and northeastern parts of Montana. Scattered thunder-storms often cause some runoff at the small area crest-stage gage sites. These same storms, however, may be of such small extent that their effect on the larger drainage areas is negligible. Therefore, it has been assumed that the composite frequency curve for the long-term stations as shown in figure 1 is applicable for all sizes of drainage areas. More record at the crest-stage gages should prove whether or not the assumption is valid.

Derivation of mean annual flood.--In order to use the regional flood-frequency curve, a study was made of the basin characteristics that might effect the determination of the mean annual flood.

The drainage area was the first characteristic considered, and was found to correlate fairly well with the mean annual flood. Substantial error would result, however, from estimating the mean annual flood from drainage area along.

In the original report, the mean altitude of the drainage basin was found to have correlative value. Further investigation has found a more easily determined basin elevation figure which also has correlative value. This is the elevation at the point seven-tenths

of the meander length of the main stream course upstream from the gage. The meander lengths of streams above the gage sites were found by use of a map measure.

Another factor found to have correlative value was the inclination, or fall, of the stream. The inclination of a stream is computed by subtracting the elevation of the stream at the gage from the elevation at seven-tenths of the meander length of the main stream course to obtain a difference in elevation. This difference is then divided by the total meander length of the main stream course, in miles, to give a factor which is called inclination, in feet per mile.

The direction of flow, or aspect of the basin, was also found to have correlative value. Different values were selected for different sectors of the compass, ranging from 10 to 40. A drawing showing the locations of the values to be used can be found on the K_D diagram in figure 3.

The factors used in the multiple correlation for the different basin characteristics are tabulated in table 1.

Formula.--The formula for mean annual flood as derived from the 24 gaging stations by multiple correlation is:

$$Q_{2.33}=751.6A^{0.553} \quad E^{-0.133} \quad I^{-0.362} \quad D^{-0.301}$$

where A = drainage area, in square miles

E = elevation at 7/10 meander length of main stream course, in feet

I = inclination, in feet per mile

D = direction of flow, in units.

The standard error of estimate ranges between 45 percent and -31 percent.

For ease of application, the formula can be given the general form: $Q_{2,33} = K_A K_E K_I K_D$, where the K values are derived from the appropriate K diagrams as found in figures 3 and 4. An example of the use of the K diagrams is shown in figure 4.

Use of composite frequency curve.--After the mean annual flood has been computed, the magnitude of the flood for the selected frequency is determined. Select the flood ratio that corresponds to the desired recurrence interval from figure 1. This ratio is multiplied by the mean annual flood, and the result is the magnitude of the flood that can be expected to be equalled or exceeded on the average of once in the number of years of the selected recurrence interval.

Limitations--The results given herein for computing the magnitude and frequency of floods should be considered provisional and subject to substantial error. On possible error may be in the assumption that the composite frequency curve for the long-term stations (see fig. 1) is applicable for all sizes of drainage areas. Because of this possible error, it is suggested that the formula given herein be used only for drainage areas from 1 to 100 square miles. For drainage areas greater than 100 square miles, the report entitled, "Floods in Eastern Montana, Magnitude and Frequency", should be used. As more crest-stage gage stations become rated and the length of record increased, these data will be included to add confidence to the present study and will undoubtedly lead to revisions and improvement.

It is further advised that the elevation characteristic be limited to 5,000 feet above mean sea level. Extension of any of the curves beyond the range of data used in the derivation of the formula is not advised. Also, use of the formula for streams outside the shaded area shown in figure 1 of the original report is not recommended.

The results given herein should be used only as a guide, not as an exact solution for computing the magnitude and frequency of floods in eastern Montana.

Table 1-Factors used in the multiple correlation of mean annual flood with basin characteristics

Sta. No.	Station	Mean Annual Flood $Q_{2.33}$	Drainage Area A	Elevation at 0.7L	Inclination I	Direction of Flow D
1	N. F. Musselshell River near Delpine	115	38.4	6,450	89.2	10
2	Dry Creek near Van Norman	5,000	2,530	2,840	7.5	20
3	Rock Creek at international bdry	970	242	2,970	14.5	20
4	Wolf Creek near Wolf Point	1,320	244	2,660	20.3	10
5	Redwater Creek at Circle	1,300	542	2,670	8.5	30
6	E.F. Poplar River at international bdry	1,000	256	2,610	5.3	10
7	Poplar River near Poplar	4,600	3,070	2,500	5.0	10
8	Big Muddy Creek at Daleview	1,850	330	2,400	11.2	10
9	Pryor Creek near Billings	620	425	4,360	25.6	30
10	Soap Creek near St. Xavier	370	111	3,800	42.5	30
11	Pass Creek near Wyola	380	119	5,000	67.1	30
12	L. Bighorn River near Crow Agency	1,750	1,190	4,500	20.8	30
13	L. Powder River near Broadus	1,600	2,000	3,880	9.1	30
14	L. Missouri River near Alzada	2,050	780	3,930	9.7	30
15	Beaver Creek at Wibaux	1,400	351	3,050	9.1	40
17	Wheatland No. 2 near Harlowton	62	2.8	5,300	85.7	10
19	Petroleum No. 2 near Winnett	50	2.32	2,780	40.0	10
20	Petroleum No. 3 near Winnett	30	0.81	2,780	60.0	10
21	Disjardin Coulee near Malta	35	3.5	2,500	62.9	40
22	E.F. Duck Creek near Brockway	76	12.4	2,900	29.4	40
24	Box Elder Creek near Plentywood	52	9.4	2,340	31.1	30
27	Spring Cr at highway 16 nr Plentywood	205	16.9	2,290	30.0	30
28	Wets Creek near Billings	56	9.14	4,000	30.7	20
29	Yellowstone No. 1 near Billings	91	2.58	3,800	15.0	20

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4	Wolf Creek near Wolf Point	1,320	244	2,660	20.3	10
5	Redwater Creek at Circle	1,300	542	2,670	8.5	30
6	E.F. Poplar River at international bdry	1,000	256	2,610	5.3	10
7	Poplar River near Poplar	4,600	3,070	2,500	5.0	10
8	Big Muddy Creek at Daleview	1,850	330	2,400	11.2	10
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Figure 1.-- Composite flood-frequency curve for eastern Montana from report entitled "Floods in Eastern Montana, Frequency and Magnitude".

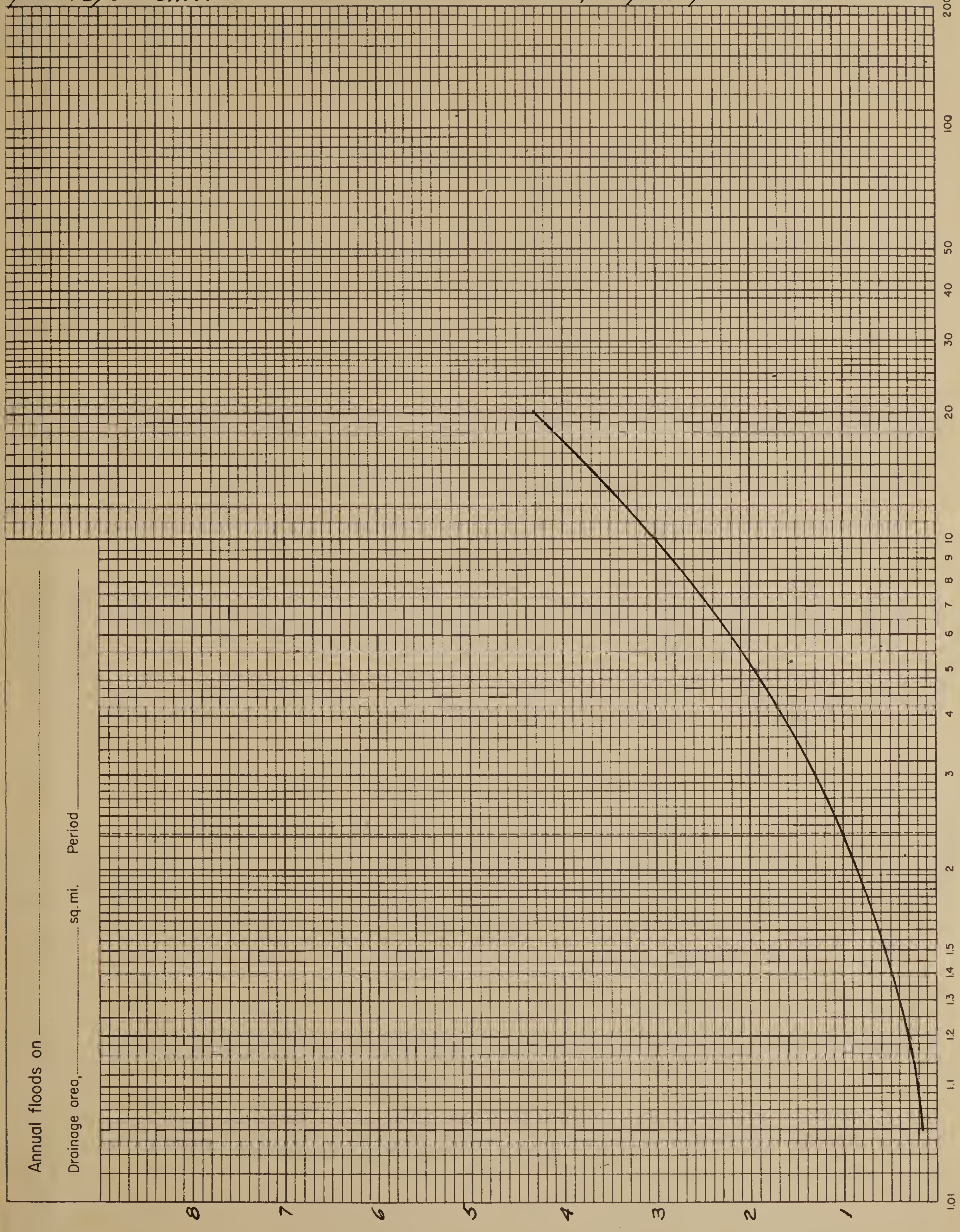
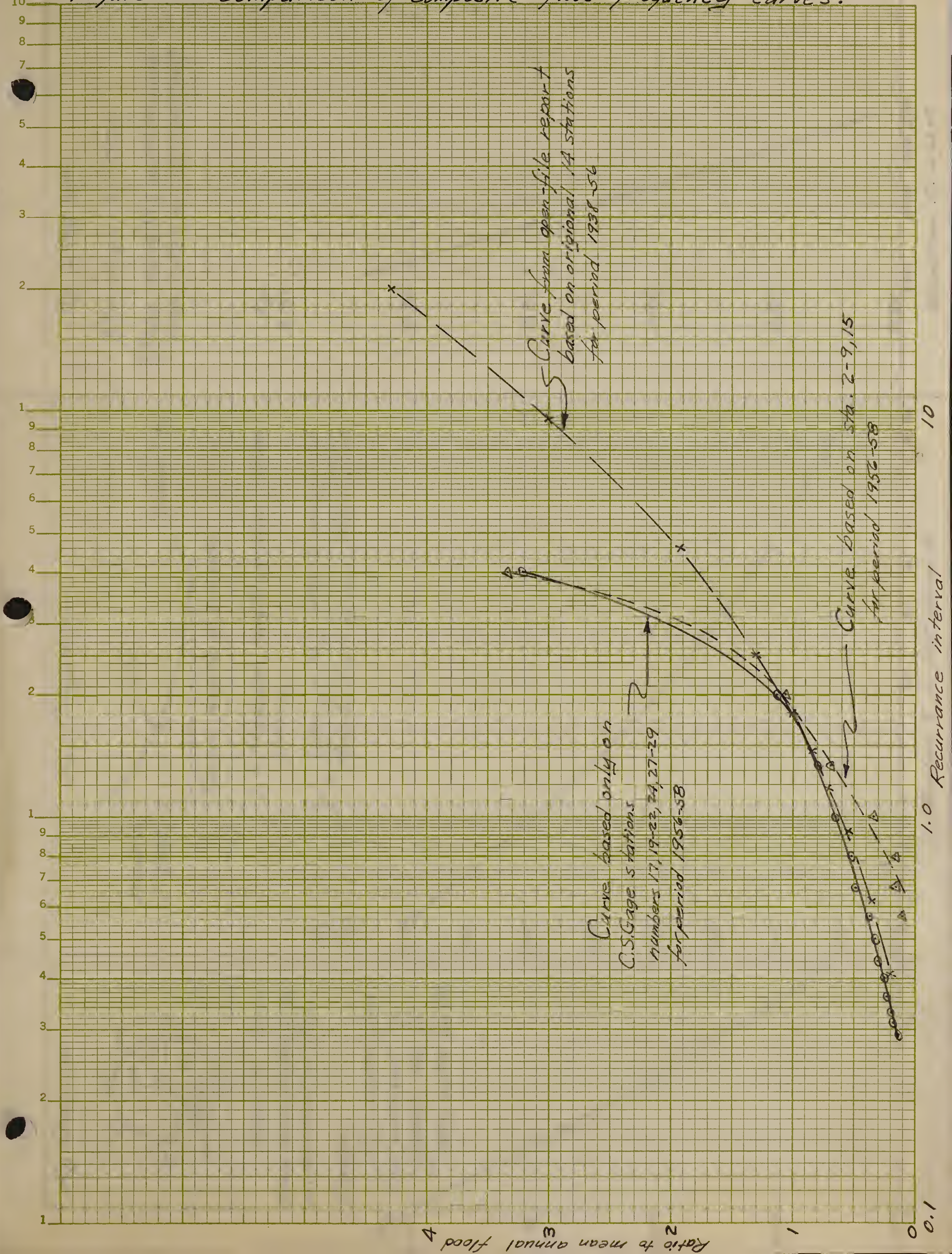


Figure 2.-- Comparison of composite flood-frequency curves.



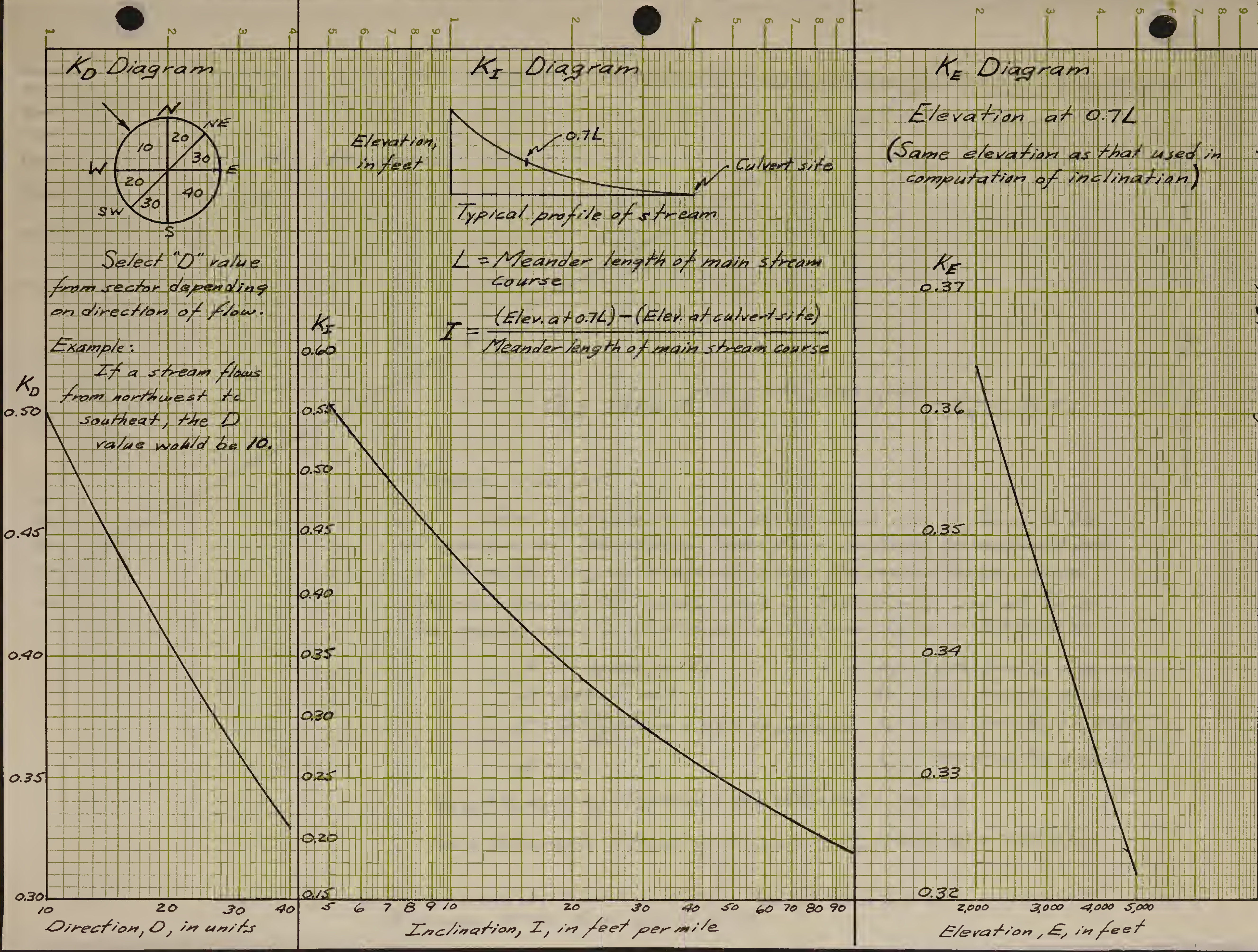


Figure 3.-- K_E; K_I, K_D Diagrams.

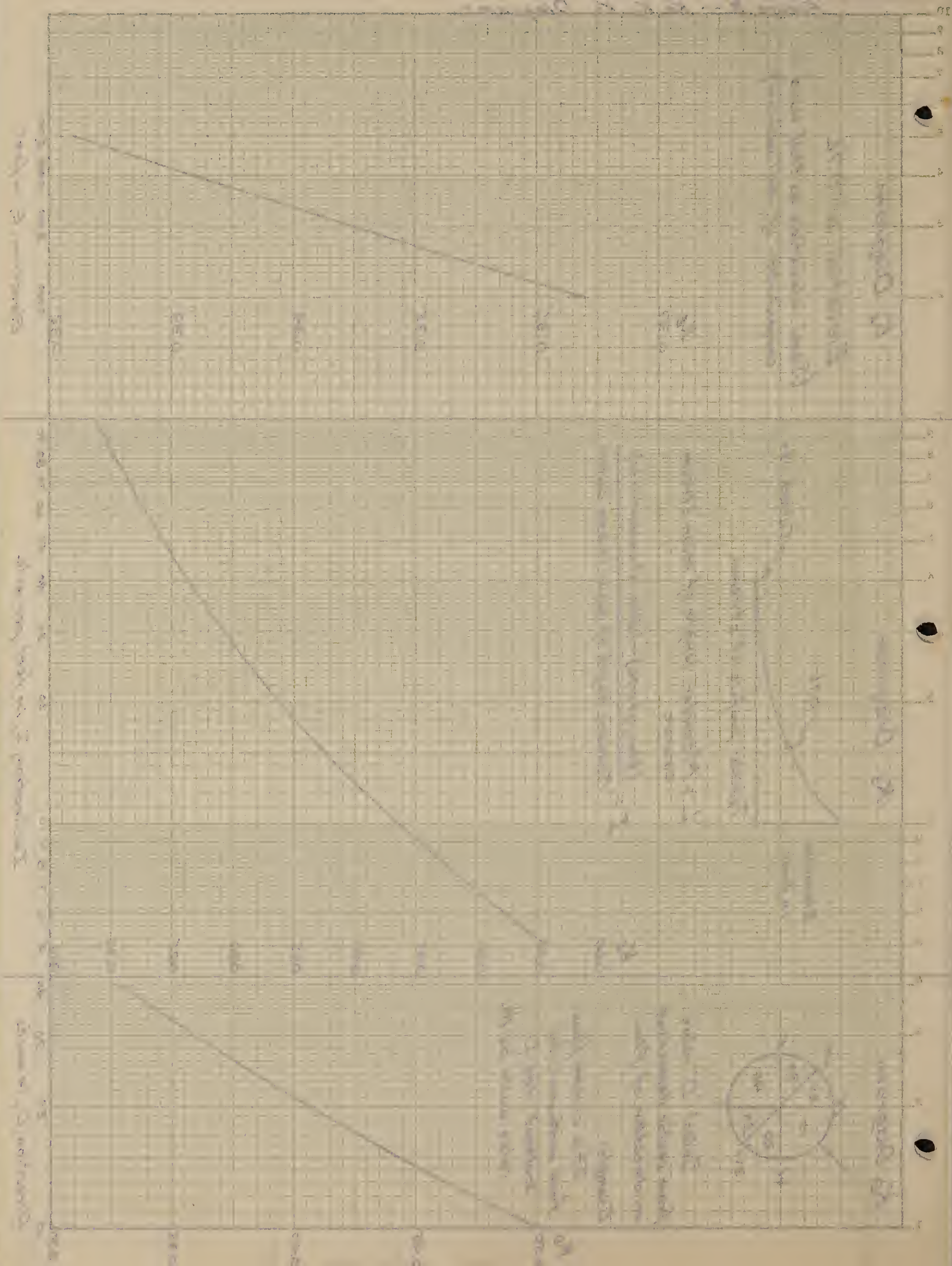
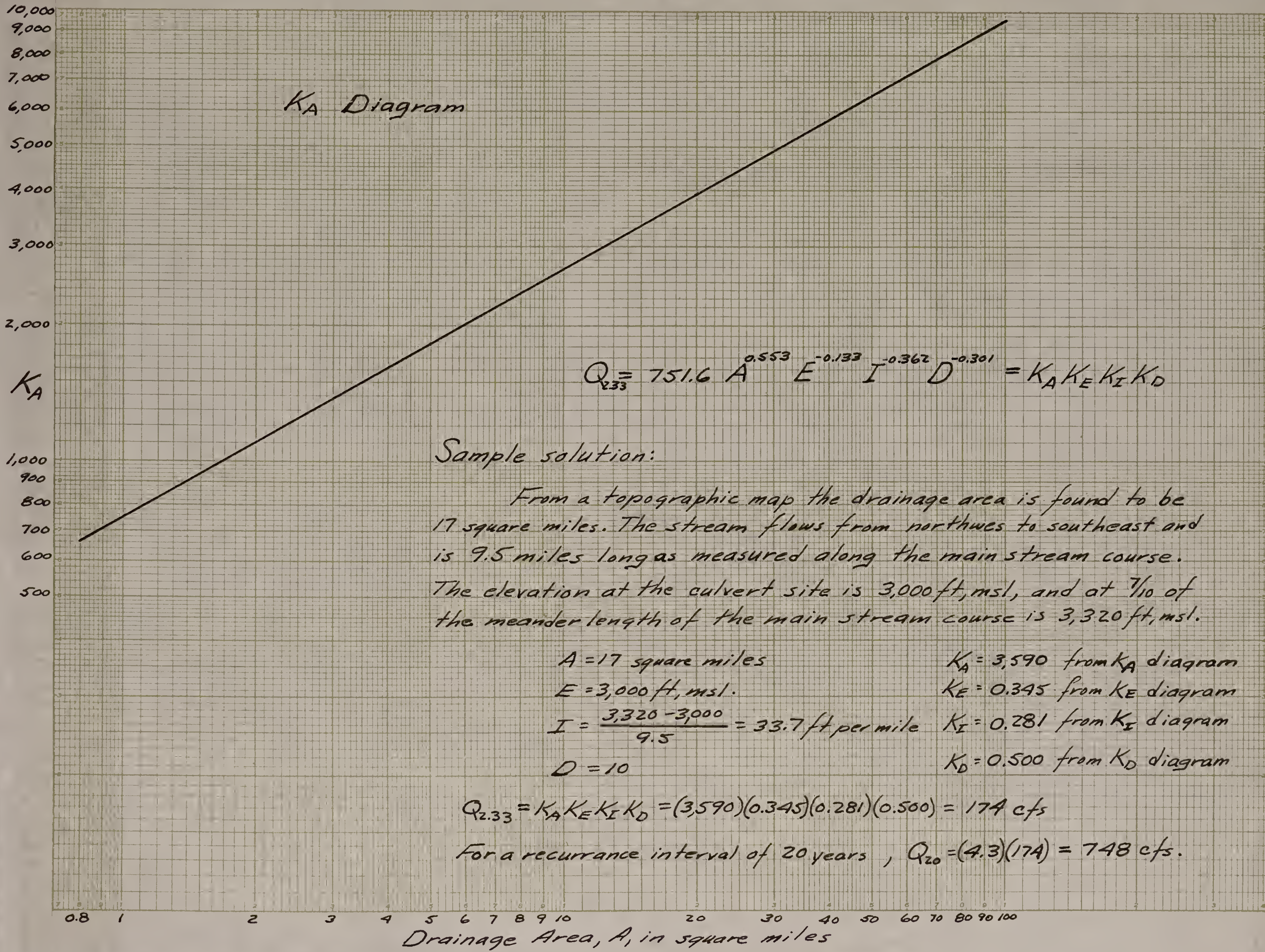


Figure 4.-- K_A Diagram



$$Q_{2.33} = 751.6\, A^{0.553}\, E^{-0.133}\, I^{-0.362}\, D^{-0.301} = K_A K_E K_I K_D$$

Sample solution:

From a topographic map the drainage area is found to be 17 square miles. The stream flows from northwes to southeast and is 9.5 miles long as measured along the main stream course. The elevation at the culvert site is 3,000 ft, msl, and at 7/10 of the meander length of the main stream course is 3,320 ft, msl.

$A = 17$ square miles — $K_A = 3{,}590$ from K_A diagram

$E = 3{,}000$ ft, msl. — $K_E = 0.345$ from K_E diagram

$I = \dfrac{3{,}320 - 3{,}000}{9.5} = 33.7$ ft per mile — $K_I = 0.281$ from K_I diagram

$D = 10$ — $K_D = 0.500$ from K_D diagram

$Q_{2.33} = K_A K_E K_I K_D = (3{,}590)(0.345)(0.281)(0.500) = 174$ cfs

For a recurrance interval of 20 years, $Q_{20} = (4.3)(174) = 748$ cfs.